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Fabrication of SiGe quantum wires by self-assembled local molecular beam growth

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Abstract. One-dimensional SiGe structures were grown by molecular beam epitaxy on mesa-patterned Si (100) and (111) substrates. The effect of temperature and deposition rate on faceting of local epitaxial Si and SiGe structures was studied in temperature range from 450°C to 900°C. Scanning electron microscopy revealed that the increase of growth temperature and/or the decrease of deposition rate result in faceting of the growing structures. Epitaxial structures with Si_{0.75}Ge_{0.25} quantum wires 4 nm in thickness and 30–50 nm in width separated by 30-nm Si barriers were grown. Low-temperature luminescence spectra of these structures were obtained.

Introduction

Common lithographic techniques are hardly suitable for fabrication of the quantum-size structures because of the limited spatial resolution of these methods. One of the possible ways to obtain the low-dimensional structures is a self-assembled growth. In recent years, a series of self-assembled growth techniques have been developed: growth on faceted substrates [1], growth on V-groove patterned substrates [2], and shadow-mask molecular beam epitaxy [3]. In this work, we studied the self-assembled molecular beam epitaxy of Si and SiGe layers on mesa-patterned Si (001) and (111) substrates under various growth conditions.

1 Experimental procedures

The samples were grown by molecular beam epitaxy on p-type Si (001) and (111) wafers patterned to form mesa stripes from 0.25 to 12 μm in width and 400 μm in length oriented along $\langle 011 \rangle$ direction. The mesa stripe pattern was formed by electron beam lithography and reactive ion etching with Al etch masks in SF₆/O₂ plasma. The grown structures were analyzed by scanning and transmission electron microscopy, secondary ion mass-spectrometry, and low-temperature photoluminescence.

2 Results and discussion

For (001) substrates, we found that $\{111\}$ facets form on the lateral sides of the epitaxial layer during growth at a rate of 15 nm/min and the substrate temperature above 500°C (Fig. 1).

At the temperature below 500°C, the lateral faceting was not observed. The decrease in growth rate down to 3 nm/min leads to the facet formation at temperatures below 450°C. The bulges bounded by the $\{111\}$ facets grow on the lateral sides of the epitaxial layer. We observed no appearance of $\{311\}$ facet planes at the temperatures about 800°C, as was reported in [4].

In the case of the (111) substrates, the facets also form at the temperatures above 500°C. The epitaxial structures grown at 550°C with a rate of 20 nm/min are asymmetric. Within the accuracy of measurements (about 3°), the facets make the angles

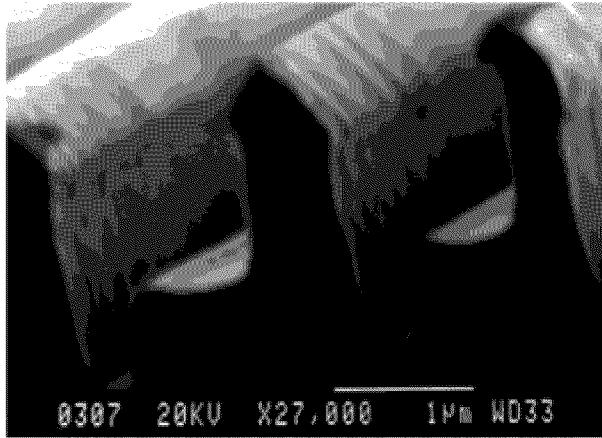


Fig 1. Typical epitaxial structure grown at 800°C.

of 48° and 74° with the substrate. Consequently, the structure may be bounded by the $\{331\}$ and $\{115\}$ or $\{001\}$ and $\{111\}$ planes, respectively, because the angles between these pairs of planes and the $\{111\}$ substrate are almost the same. Since $\{111\}$ and $\{100\}$ are the most stable surfaces [5], most likely these facets are $\{001\}$ and $\{111\}$. The epitaxial structures grown at 500–900°C with a rate of 5–20 nm/min are bounded by the same facets.

Doping of the growing layers with Ge up to 10 percents (i.e. introduction of strain to the growing film) has no influence on the faceting of the crystallization front.

Using the revealed regularities of the self-assembled epitaxial growth, structures with $\text{Si}_{0.75}\text{Ge}_{0.25}$ quantum wires 4 nm in thickness and 30–50 nm in width separated by 30-nm Si barriers were grown. Low-temperature luminescence spectra of these structures were obtained.

3 Conclusion

Thus, we have demonstrated the possibility to control the shape of the epitaxial structures by varying the growth conditions and to prepare one-dimensional structures down to several tens of nanometers in width on the top of the epitaxial layer using self-assembled epitaxy on relatively wide (about micrometer) mesa substrates.

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